AD A

Exhaust Emissions from a 6.5L Diesel Engine Using Synthetic Fuel and Low-Sulfur Diesel Fuel

INTERIM REPORT
TFLRF No. 370

by

Edwin A. Frame
Matthew G. Blanks
U.S. Army TARDEC Fuels and Lubricants Research Facility (SwRI)
Southwest Research Institute
San Antonio, TX

for

U.S. Army TARDEC
National Automotive Center (NAC)
Warren, MI

Under Contract to

U.S. Army TARDEC
Petroleum and Water Business Area
Warren, MI

Contract No. DAAE-07-99-C-L053 (WD23)
SwRI Project No. 03.03227.23

December 2003

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Approved by:

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13. ABSTRACT (Maximum 200 words)

Synthetic fuel, designated S-5, was evaluated for exhaust emissions and fuel consumption in a 6.5L diesel enigne. The S-5 fuel produced substantial reduction in exhaust particulate matter compared to low-sulfur certification diesel fuel over two different transient test cycles. In general, the S-5 fuel produced lower exhaust emission levels and slightly reduced brake specific fuel consumption over both test cycles.

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EXECUTIVE SUMMARY

Synthetic JP-5 fuel (designated S-5 fuel) was evaluated for exhaust emissions and fuel consumption effects in a 6.5L diesel engine used in the HMMWV. For comparison purposes a low-sulfur certification diesel fuel was also tested. Each fuel was conducted with duplicate tests for both FTP on-highway (heavy-duty) and SAT nonroad transient test cycles. The S-5 fuel produced lower exhaust emission levels and slightly reduced brake specific fuel consumption over both test cycles. The exhaust particulate matter was substantially reduced (52-55%) with S-5 fuel compared to the reference low sulfur diesel fuel.

FOREWORD/ACKNOWLEDGMENTS

This work was performed by the U.S. Army TARDEC Fuels and Lubricants Research Facility (TFLRF) located at Southwest Research Institute (SwRI), San Antonio, Texas, during the period February 2003 through October 2003 under Contract No. DAAE-07-99-C-L053. The work was funded by the U. S. Army TARDEC National Automotive Center (NAC). The project was administered by the U.S. Army Tank-Automotive RD&E Center, Petroleum and Water Business Area, Warren, Michigan. Mr. Luis Villahermosa (AMSRD-TAR) served as the TARDEC contracting officer's technical representative. Ms. Pat Muzzell served as the project technical monitor.

Test results presented in this report were generated by the Department of Emissions Research (DER), Automotive Products and Emissions Research of Southwest Research Institute (SwRI), for the U. S. Army TARDEC Fuels and Lubricants Research Facility (TFLRF). This work was conducted under the DER management of Mr. Terry L. Ullman. Mr. John J. Elizondo, Staff Technician, Mr. Juan G. Vega, Technician, and Mr. Rodney E. Grinstead provided primary technical support.

The authors would like to acknowledge the administrative and report-processing support provided by Wendy Mills.

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I. BACKGROUND AND OBJECTIVE

Fischer-Tropsch (F-T) process synthetic fuels, first produced in the 1920's (1)*, were used by Germany during WWII and South Africa during its embargo to offset petroleum shortages. Synthetic JP-8 is a clean fuel with no sulfur or aromatics, which has historically cost too much to compete with petroleum fuel. Since the mid-1990s, the world's major energy companies have started to develop updated F-T processes that are less expensive to build and operate. The goal is to produce a sulfur-free product for meeting air quality requirements, and to consume natural gas that can no longer be flared due to environmental rules. Synthetic fuel chemistry differs significantly from petroleum fuels since F-T synthetic fuels are free of aromatic and sulfur compounds. These fuel property differences should result in reduced exhaust emissions from military diesel engines. Synthetic F-T fuels have demonstrated reduced diesel exhaust particulate matter in other research (2-11).

This report addresses the exhaust emissions characteristics from a military diesel engine using a synthetic JP-5 fuel, as compared to low sulfur reference diesel fuel.

II. PROCEDURE

A new, 6.5 liter, heavy-duty diesel engine (SN 2722) was used for this testing. Based on the heavy-duty FTP transient exhaust emissions observed for this engine, it was calibrated to meet the 1991 heavy-duty exhaust emission standards. Engine specifications are given in Table A-1 of Appendix A. Prior to this project, the engine had accumulated the following hours of operation: a 100-hour "break-in" procedure, six 11-mode tests, and three nonroad transient tests. These operations accumulated approximately 110 hours on the engine. Figure 1 shows the installed engine.

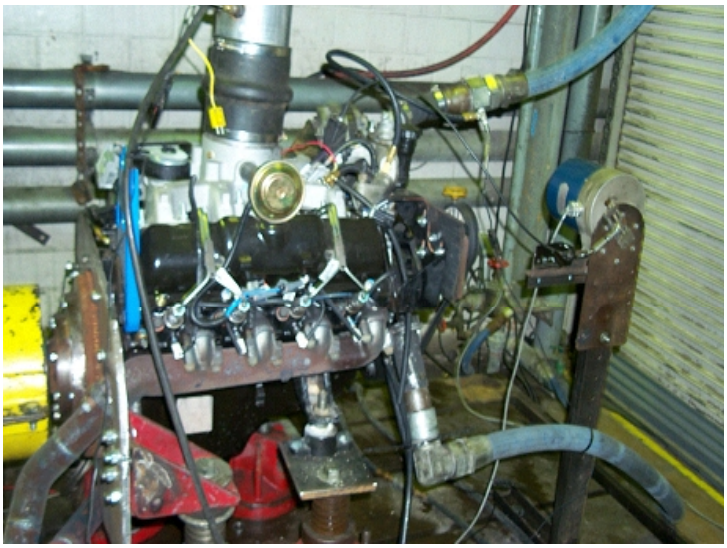

Figure 1. Installed 6.5L Heavy-Duty Diesel Engine

A. Test Fuels

Two fuels were used in emission testing of the 6.5L engine. Low-sulfur certification diesel (LSCD, EM-4816-F), was supplied by DER. Properties for the LSCD are listed in Table 1.

Table 1. Properties of Low-Sulfur Certification Diesel Fuel EM-4816-F

Item Tested	ASTM Test Method	CFR Specification * Type 2-D	SwRI Analysis
Cetane Number	D613	40-48	47.9
Distillation Range:			
IBP °C	D86	171-204	189.7
10% Point, °C	D86	204-238	223.0
50% Point, °C	D86	243-282	259.7
90% Point, °C	D86	293-332	309.2
EP, °C	D86	321-366	358.3
Gravity, API	D287	32-37	36
Total Sulfur, %	D2622	0.03-0.04	0.037
Hydrocarbon Composition:			
Aromatics, %	D1319	10[a]	30.9
Paraffins, Naphthenes, Olefins	D1319	90[b]	69.1
Flashpoint, °C	D93	54 (min.)	62
Viscosity, 40°C, mm^2/s	D445	2.0-3.2	2.48

* Diesel fuel specification as in CFR89 Appendix A, Table 4 for heavy-duty nonroad engines
[a] Minimum
[b] Remainder

Synthetic JP-5 fuel, Code No. S-5-03-001 (unadditized), batch 0001, lot 0003, was produced by Syntroleum Corporation in Tulsa, OK. The properties of the base S-5 fuel (designated AL-26943) are presented in Table 2. Syntroleum provided this information.

The S-5 fuel was additized with the maximum recommended concentration of 22.5 mg/L per MIL-PRF-25017 QPL to protect the rotary fuel injection pump during the tests.

Table 2. Properties of S-5 Test Fuel, AL-26943, S-5X-03-001, non-additized, batch 0001, lot 0003

Property	Method	Contract Specification	Typical	Actual
Kinematic Viscosity @-20°C, mm^2/s	D-445	8.0 max	5.6	6.2
Aromatics (vol%)	D-1319	5.0 max	<1.0	0.9
Net Heat of Combustion MJ/kg	D-4529	42.8 min	44.2	44.1
Smoke Point, mm	D-1322	25.0 min	>43	>43
Aromatics by ^1H NMR mol%	D-5292	.1%	<0.05	ND
Olefins Vol % (g Br2/100g)	D1319 (D1159)	1.0 (<1.0) max	<0.5 (0.2)	0.6
Hydrogen Content wt %	D5291	13.4 min	15.5	15.6
Distillation Temp °C	D86 (D2887)			
Initial Boiling Point		Report	193 (Report)	186 (154)
10% Recovered		205 max	197 (Report)	196 (172
20% Recovered		Report	202 (Report)	201 (186)
50% Recovered		Report	230 (Report)	220 (224)
90% Recovered		Report	252 (Report)	254 (272)
Final Boiling Point		300 max	274 (Report)	271 (293)
Residue (vol%)		Report	<2	1.1
Loss (vol%)		Report	<2	0.3
Density (kg/L @15°C)	D-4052	0.75-0.77	0.759	0.765
Flash Point °C	D-93	60 min	64	64
Total Sulfur, max	D-5453	0.3 max	<0.0001	<0.0001
Freezing Point°C	D-5972	-47 max	-49	-53
Saybolt Color	D-156	Report	+30	+30
Calculated Cetane Index	D-976	Report	<60	69.3
BOCLE,mm	D-5001	NR		0.95
SLBOCLE, g	D-6078	NR		967
HFRR, µm	D-6079	NR		609
NR=Not Required	ND=Not Determined			

B. Emission Testing

The engine was run at 3,400 rpm using LSCD at full load conditions for ten minutes to purge the previous test fuel from the system. A power validation sequence was performed at 3,400 rpm yielding acceptable performance. Emission instrumentation, torque meter, signal-conditioning systems, and constant volume sampler (CVS) gaseous and particulate sampling systems were checked and calibrated before testing. The test plan used for accumulating emissions data from the engine is given in Table 3.

Table 3. Test Plan for Accumulating Emissions Data

Step	Description
1	Perform emission instrument calibrations as required. Calibrate torquemeter and check signal-conditioning systems. Validate CVS gaseous and particulate sampling systems using propane recovery techniques.
2	Perform fuel change procedure to LSCD (EM-4816-F) supplied by DER. Change fuel filters, purge fuel supply, etc.
3	Operate engine at rated speed and load for approximately 10 minutes, then power validate engine.
4	Conduct transient "full throttle" torque map from low to high-idle and save resulting transient command cycle. The torque map generated with LSCD will be used for all transient test cycles.
5	Conduct duplicate FTP nonroad transient tests. Measure: HC, CO, CO2, NOx, PM, and fuel consumption.
6	Conduct duplicate SAT nonroad transient tests. Measure: HC, CO, CO2, NOx, PM, and fuel consumption.
7	Perform fuel change procedure to S-5 synthetic fuel supplied by TFLRF. Change fuel filters, purge fuel supply, etc.
8	Repeat Steps 3-6. Save resulting S-5 Synthetic fuel torque map for reference only.

Duplicate hot-start FTP transient emission tests, using each of the two fuels, were conducted according to the EPA FTP, as specified in the Code of Federal Regulations (CFR), Title 40, Part 86, Subpart N "Emission Regulations for New Otto-Cycle and Diesel Heavy-Duty Engines: Gaseous and Particulate Exhaust Test Procedures." Regulated emissions of HC, CO, CO2, NOx and PM were measured using analyzers and techniques listed in Table 4.

Table 4. List of Measured Emissions and Analytical Methods

Pollutant	Abbreviation	Analytical Method
Hydrocarbon	HC	Heated Flame Ionization Detector
Carbon Monoxide	CO	Non-Dispersive Infrared Analyzer
Carbon Dioxide	CO2	Non-Dispersive Infrared Analyzer
Oxides of Nitrogen	NOx	Chemiluminescent Analyzer
Particulate Matter	PM	Micro Balance

Duplicate hot-start nonroad transient emission tests, using each of the two fuels, were also conducted according to EPA FTP, as specified in the CFR, Title 40, Part 86, Subpart N with the exception of replacing the EPA "Engine Dynamometer Schedule for Heavy-Duty Diesel Engines" given in the CFR, Title 40, Appendix I, Subpart F(2) with the proposed San Antonio Transient (SAT) nonroad engine dynamometer schedule. The SAT normalized schedule is given in Figure 2. Regulated emissions of HC, CO, CO2, NOx and PM were again measured using the analyzers and techniques from Table 3.

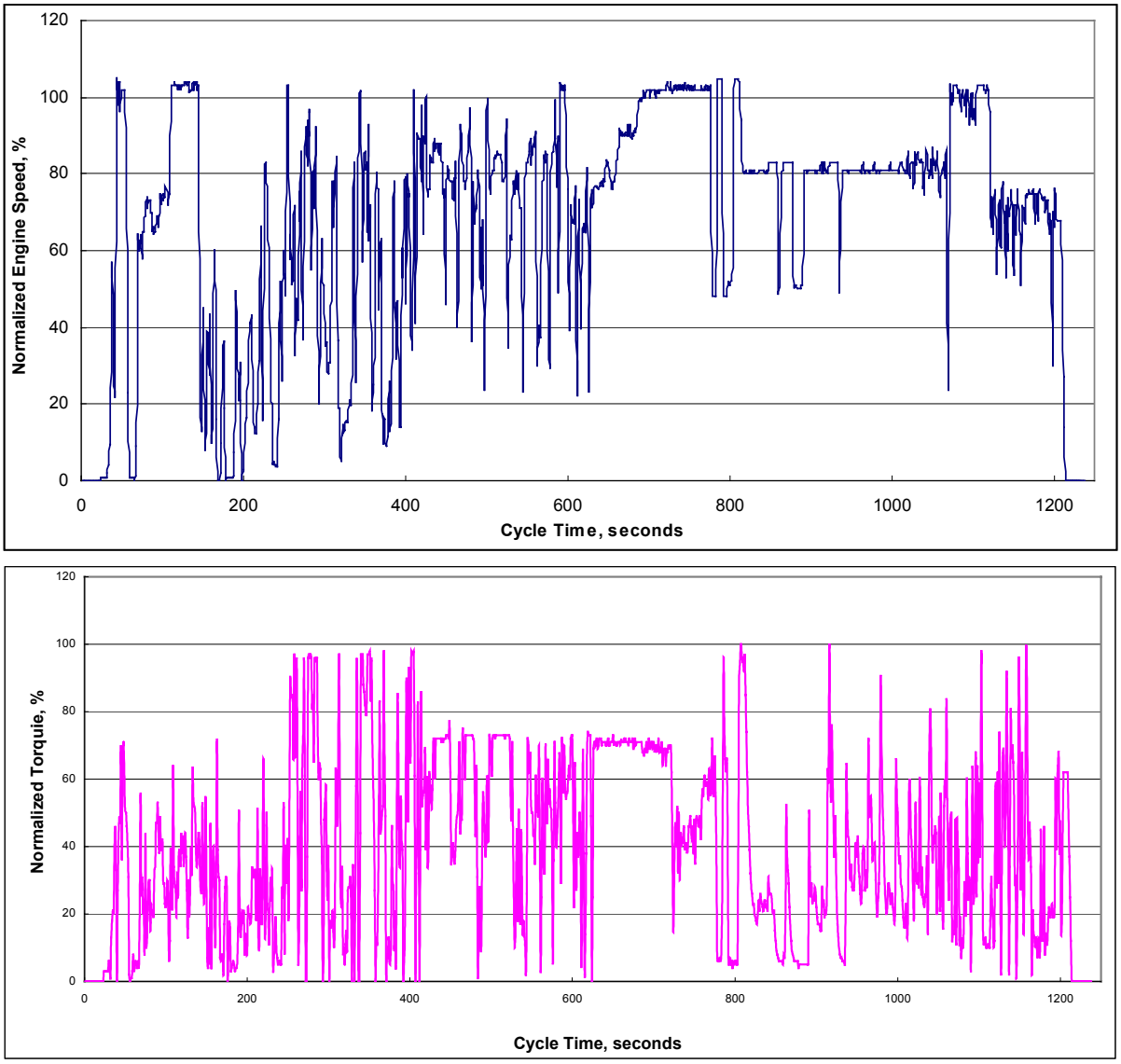

Figure 2. Normalized Nonroad SAT Dynamometer Schedule

Torque-maps for LSCD and S-5 were created at "wide-open-throttle" by increasing the engine's speed from 600 rpm to 3400 rpm at a rate of eight rpm per second. Results of these maps are given in Figure 3 and Table 5. Note that the transient command cycles used for emission testing both fuels were generated from the LSCD torque map data. The S-5 synthetic fuel torque-map was created for reference purposes only.

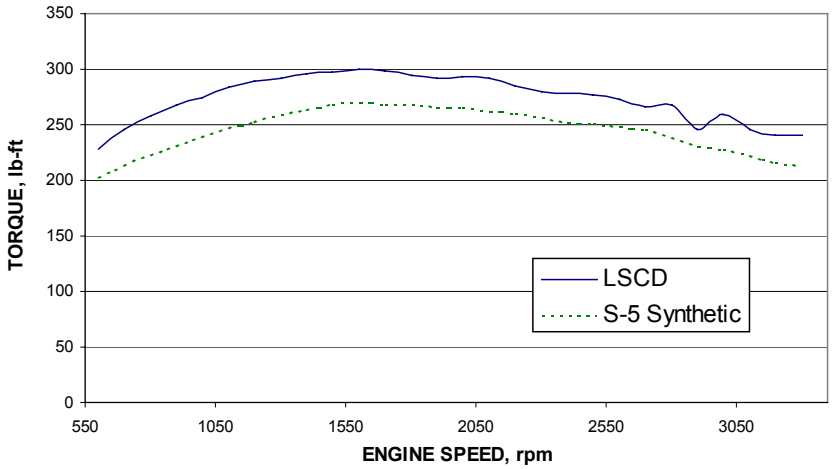

Figure 3. Transient Torque Maps on Two Fuels from a 6.5L Heavy-Duty Diesel Engine

Table 5. Transient Torque Maps on Two Fuels from a 6.5L Heavy-Duty Diesel Engine

TORQUE MAPS ON TWO TEST FUELS FROM A 6.5L HEAVY-DUTY DIESEL ENGINE,		
ENGINE SPEED, rpm	TORQUE, lb-ft	
	Fuel: LSCD (*) EM-4816-F	Fuel: S-5
	MAP # 688	MAP # 698
600	228	202
700	246	213
800	258	223
900	267	231
1000	274	239
1100	284	247
1200	289	253
1300	293	260
1400	296	264
1500	298	269
1600	300	270
1700	298	270
1800	295	269
1900	292	266
2000	294	266
2100	292	262
2200	285	260
2300	280	257
2400	278	253
2500	277	251
2600	273	248
2700	267	246
2800	267	240
2900	246	231
3000	259	229
3100	246	224
3200	240	216
3300	240	213

(*) The EM-4816-F fuel torque-map was the basis for generating the transient command cycles used in emission tests for both fuels.

C. Test Cycle Generation

During previous tests with this 6.5 liter engine, dynamometer failure was encountered that was believed to be associated with the high engine speed necessary to reach high idle (3,900 rpm). Arrangements were made with TFLRF to limit the engine speed to 3,400 rpm for this study. Due to this limitation, the programmed rated speed for all SAT tests was set at 3,250 rpm. This setting produced a maximum SAT cycle speed of 3,377 rpm. The programmed rated speed for all FTP tests was set at 3,100 rpm. This testing produced a maximum FTP cycle speed of 3,412 rpm. Test cycles for both the SAT and FTP tests were generated based on an engine torque-map using LSCD.

III. RESULTS

This section gives the results for the pollutants measured from the 6.5L heavy-duty engine operating on LSCD and S-5 synthetic fuels over the FTP on-highway transient and the SAT nonroad transient cycles. Results for HC, CO, CO2, NOx, and PM emissions are given in Table 6. Note that all of the transient test cycles were generated based on engine performance with the LSCD fuel. Appendix B contains the computer printouts for each test.

Table 6. Emission Results of Heavy-Duty Transient FTP And SAT Nonroad Tests from a 6.5L Heavy-Duty Diesel Engine

Test Type	Fuel Type	Test Number	Brake Specific Emissions (g/hp-hr)					Ref. Work hp-hr	Work hp-hr	BSFC lb/hp-hr
			HC	CO	CO2	NOx	PM			
SAT	LSCD (EM-4816-F)	691 SATCert.a	0.727	3.24	805	3.52	0.152	17.95	16.8	0.563
		692 SATCert.b	0.712	3.22	770	3.55	0.157		16.7	0.539
	S-5 Synthetic	705 SATSyn.a	0.190	1.25	732	3.08	0.075		17.7	0.521
		706 SATSyn.b	0.213	1.31	738	2.93	0.074		17.4	0.526
FTP	LSCD (EM-4816-F)	696 FTPCert.a	0.980	3.50	775	3.58	0.254	9.61	9.3	0.543
		697 FTPCert.b	0.945	3.40	782	3.57	0.252		9.3	0.548
	S-5 Synthetic	702 FTPSyn.a	0.336	1.86	751	3.01	0.114		9.5	0.536
		703 FTPSyn.b	0.378	1.87	753	3.23	0.114		9.4	0.537

IV. SUMMARY/CONCLUSIONS

Emission testing was performed using a 6.5L heavy-duty diesel engine operating on two fuels. Each fuel was evaluated with duplicate tests for both the FTP on-highway and SAT nonroad transient cycles. Table 7 gives average emissions for each two-test set along with the work produced and the fuel consumed over the cycle. Figure 4 displays the emission results for HC, CO, NOx, and PM. Figure 5 shows the % reduction in exhaust emissions and brake-specific fuel consumption when using S-5 fuel. The S-5 synthetic fuel produced lower emission levels over both test cycles.

Table 7. Summary of Emission Results From a 6.5L Heavy-Duty Engine Operating over FTP and SAT Transient Test Cycles

Test Type	Fuel Type	Brake Specific Emissions (g/hp-hr)					Ref. Work hp-hr	Work hp-hr	BSFC lb/hp-hr
		HC	CO	CO2	NOx	PM			
SAT	LSCD (EM-4816-F)	0.72	3.23	788	3.53	0.155	17.95	16.7	0.551
	S-5 Synthetic (FT-100)	0.20	1.28	735	3.01	0.074		17.5	0.523
FTP	LSCD (EM-4816-F)	0.96	3.45	779	3.58	0.253	9.61	9.3	0.546
	S-5 Synthetic (FT-100)	0.36	1.87	752	3.12	0.114		9.5	0.536

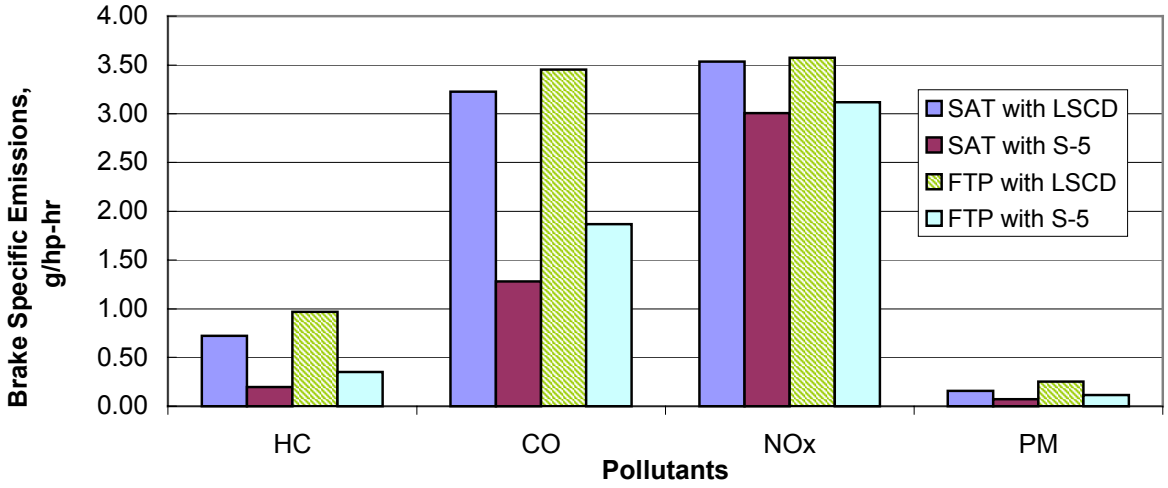

Figure 4. Summary of Emission Results from a 6.5L Heavy-Duty Engine Operating over FTP and SAT Nonroad Transient Test Cycles

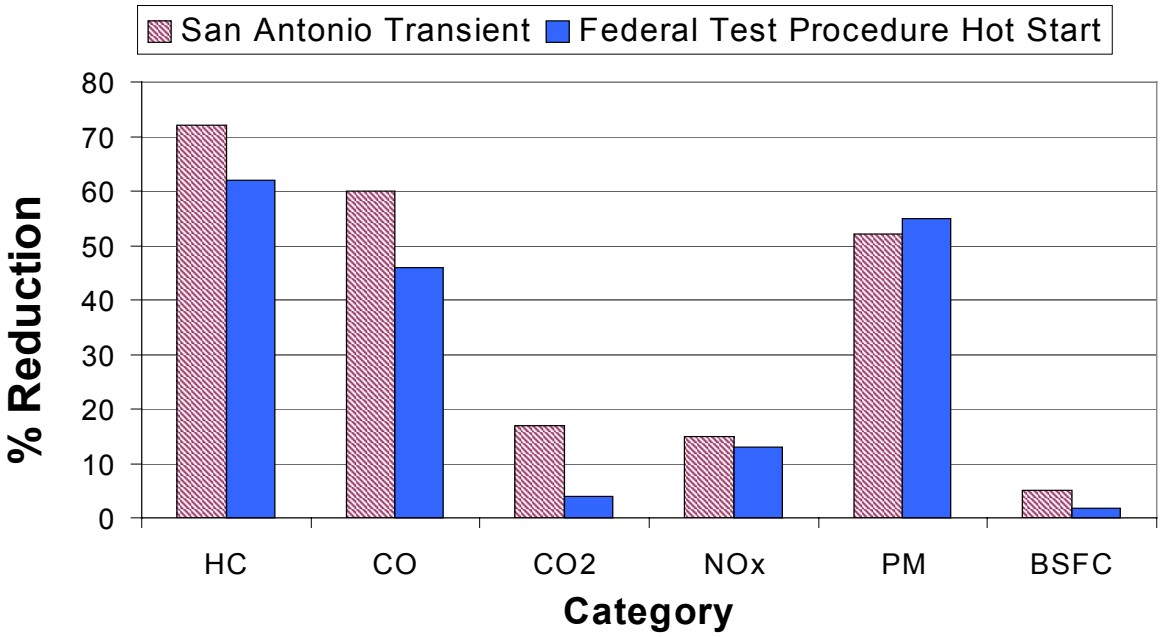

Figure 5. % Reductions with Synthetic Fuel (S-5) as Compared to Reference Low Sulfur Diesel Fuel, Heavy-Duty Engine (6.5L)

Overall, compared to the low-sulfur certification diesel fuel, the S-5 resulted in the reductions shown in Table 8.

Table 8. Pollutant Reduction Using S-5

Pollutants	SAT Nonroad Transient Cycle	FTP Transient Cycle
HC	72%	62%
CO	60%	46%
CO2	17%	4%
NOx	15%	13%
PM	52%	55%

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APPENDIX A

6.5L HEAVY-DUTY DIESEL ENGINE SPECIFICATION

TABLE A-1. ENGINE SPECIFICATIONS

Make: 6.5L Diesel used in HMMWV		**Displacement:** 6.5 liters			
Model:		**Serial Number:** 2722 **Mechanical Injection**			
NO.	**TEST PARAMETER**	**SPECIFICATION**			
1	Rated Speed	3400			rpm
2	Rated Power	160	+/- □□10		hp
3	Fuel Rate at Rated Speed and Power	80			lb/hr
4	Fuel Temp. at Rated Speed and Power	min.	max.		□F
5	Rated Torque Speed	1700			rpm
6	Rated Torque	290	□□+/-15		lb-ft
7	Fuel Rate at Rated Torque Speed and Torque	47			lb/hr
8	High Idle *(governed)*	3900	□		rpm
9	Low Idle *(curb idle)*	700	□		rpm
10	CITT @ rpm *(automatic transmission application)*	NA lb-ft @			rpm
11	Cranking Speed	150			rpm
12	Water Outlet Temperature	thermostat	+/-□□5		□F
13	Pressure Drop Across Intercooler	NA □			"H_2O
14	Air Temperature After Intercooler	min. NA	max. NA		□F
15	Engine Oil *(SAE rating)* / Sump Capacity	15w40 /			
16	Engine Coolant Type *(water, %water + %glycol, etc.)*	Water + Glycol			
17	**Intake and Exhaust Restrictions**	Part 86 Transient	Federal Smoke	Part 89[a] Nonroad	
18	Intake Restriction[b] +/-(□1.0 "H_2O)			15.3@ Rated	"H_2O
19	Exhaust Restriction[b] +/- (□ 0.1 "Hg)			7.5@ Rated	"Hg
20	Intake Restriction Location from Inlet[c]	□			Inches
21	Exhaust Restriction Location from Outlet[c]	□			Inches

[a] Or other steady-state emissions test, as follows: ISO-8178 11-MODE

[b] Provide values applicable to project. (Tolerances as shown, unless otherwise specified.) and specify tubing diameters at probes in inches as follows: Intake _____ Exhaust _____ .

[c] From Turbo if turbocharged or from Manifold if naturally aspirated.

SwRI □ Department of Emissions Research

APPENDIX B

FTP AND SAT EMISSION TEST RESULT COMPUTER PRINTOUTS FOR 6.5L HEAVY-DUTY DIESEL ENGINE USING BOTH LSCD AND S-5 SYNTHETIC FUEL

Southwest Research Institute - Department of Emissions Research
EPA Hot Transient Emission Test Results
Project No. 03-3227-301

Engine Model:
Engine Desc.: 6.5 L (395 CID) V-8
Engine Cycle: Diesel
Engine S/N:
SAT on Cert.

Test No.: 691 SATCert.a
Date: 03/12/2003 Time: 10:41
Program HDT: 4.12-R
Cell: 3 Bag Cart: 2

DIESEL Cert., EM-4816-F
HCR: 1.812 FID Resp: 1.00
H= 0.132 C= 0.868 O= 0.000 X= 0.000

Ambient/Test Cell Conditions

Barometer:	29.06	in Hg	98.4 kPa
Engine Inlet Air			
Temperature:	76.0	°F	24.4 °C
Dew Point:	59.3	°F	15.2 °C
Abs. Humidity:	77.9	gr/lb	11.1 g/kg
Rel. Humidity:	56	%	
Dilution Air:			
Temperature:	78.0	°F	25.6 °C
Abs. Humidity	78.7	gr/lb	11.2 g/kg
Rel. Humidity:	53	%	

Measured Gaseous Data

	Meter	Range	Concentration		
HC Sample	n/a		20.77	ppm	
HC Bckgrd	4.5	2	4.62	ppm	
CO	39.1	2	37.75	ppm	(Dry)
CO Bckgrd	0.7	2	0.67	ppm	
NOx Sample	n/a		24.45	ppm	(Dry)
NOx Bckgrd	1.0	1	0.25	ppm	
CO2 Sample	64.5	1	0.6196	%	(Wet)
CO2 Bckgrd	5.9	1	0.0523	%	

Corrected Concentrations

HC	16.36	ppm
CO	36.03	ppm
NOx	23.64	ppm
CO2	0.5697	%

Mass Emissions

HC	12.195	grams
CO	54.353	grams
NOx	59.031	grams
Particulate	2.559	grams
CO2	13.506	kg
Fuel	9.45 lb	4.29 kg

Sample Flows

	scfm	scmm
Blower 1 Rate:	2,188.1	61.97
Blower 2 Rate:	0.0	0.00
90 mm System:		
Gas Meter 1:	1.82	0.05
Gas Meter 2:	4.11	0.12
Sample Rate:	2.29	0.06
Total Flow Rate:	2,190.43	62.03

Particulate Data

Filter Number: 3186.0-72 (pair)
Weight Gain: 2.673 mg
Sample Multiplier: 0.957

Correction Factors

NOx Humidity CF:	1.008
Dry-to-Wet CF, Sample:	0.977
Dry-to-Wet CF, Bckgrd:	0.982
Dilution Factor:	21.70

Test Cycle Data

Sample Time:	1,253.40	sec		
Work:	16.78	hp-hr	12.51	kW-hr
Reference Work:	17.95	hp-hr	13.39	kW-hr
Total Volume (Vmix):	45,758.1	scf	1,295.90	scm

Brake-Specific Emission Results

BSHC	(Cell)	0.727 g/hp-hr	0.975	g/kW-hr
CO		3.239 g/hp-hr	4.344	g/kW-hr
NOx	(Cell)	3.518 g/hp-hr	4.718	g/kW-hr
Particulate		0.152 g/hp-hr	0.204	g/kW-hr
CO2		804.9 g/hp-hr	1,079.39	g/kW-hr
BSFC		0.563 lb/hp-hr	0.343	kg/kW-hr

Southwest Research Institute - Department of Emissions Research
EPA Hot Transient Emission Test Results
Project No. 03-3227-301

Engine Model:
Engine Desc.: 6.5 L (395 CID) V-8
Engine Cycle: Diesel
Engine S/N:
SAT on Cert.

Test No.: 692 SATCert.b
Date: 03/12/2003 Time: 11:21
Program HDT: 4.12-R
Cell: 3 Bag Cart: 2

DIESEL Cert., EM-4816-F
HCR: 1.812 FID Resp: 1.00
H= 0.132 C= 0.868 O= 0.000 X= 0.000

Ambient/Test Cell Conditions

Barometer:	29.05	in Hg	98.3 kPa
Engine Inlet Air			
Temperature:	76.0	°F	24.4 °C
Dew Point:	57.8	°F	14.3 °C
Abs. Humidity:	73.8	gr/lb	10.5 g/kg
Rel. Humidity:	53	%	
Dilution Air:			
Temperature:	79.0	°F	26.1 °C
Abs. Humidity	77.1	gr/lb	11.0 g/kg
Rel. Humidity:	50	%	

Measured Gaseous Data

	Meter	Range	Concentration		
HC Sample	n/a		20.47	ppm	
HC Bckgrd	4.6	2	4.73	ppm	
CO	38.8	2	37.46	ppm	(Dry)
CO Bckgrd	0.9	2	0.86	ppm	
NOx Sample	n/a		24.87	ppm	(Dry)
NOx Bckgrd	1.3	1	0.33	ppm	
CO2 Sample	61.5	1	0.5882	%	(Wet)
CO2 Bckgrd	5.4	1	0.0479	%	

Corrected Concentrations

HC	15.95	ppm
CO	35.62	ppm
NOx	23.99	ppm
CO2	0.5424	%

Mass Emissions

HC	11.880	grams
CO	53.718	grams
NOx	59.240	grams
Particulate	2.627	grams
CO2	12.853	kg
Fuel	9.00 lb	4.08 kg

Sample Flows

	scfm	scmm
Blower 1 Rate:	2,187.2	61.94
Blower 2 Rate:	0.0	0.00
90 mm System:		
Gas Meter 1:	1.82	0.05
Gas Meter 2:	4.12	0.12
Sample Rate:	2.29	0.06
Total Flow Rate:	2,189.51	62.01

Particulate Data

Filter Number: 3187.0-73 (pair)
Weight Gain: 2.753 mg
Sample Multiplier: 0.954

Correction Factors

NOx Humidity CF:	0.997
Dry-to-Wet CF, Sample:	0.977
Dry-to-Wet CF, Bckgrd:	0.983
Dilution Factor:	22.85

Test Cycle Data

Sample Time:	1,253.40	sec		
Work:	16.69	hp-hr	12.45	kW-hr
Reference Work:	17.95	hp-hr	13.39	kW-hr
Total Volume (Vmix):	45,739.0	scf	1,295.35	scm

Brake-Specific Emission Results

BSHC	(Cell)	0.712 g/hp-hr	0.955	g/kW-hr
CO		3.219 g/hp-hr	4.316	g/kW-hr
NOx	(Cell)	3.549 g/hp-hr	4.760	g/kW-hr
Particulate		0.157 g/hp-hr	0.211	g/kW-hr
CO2		770.1 g/hp-hr	1,032.75	g/kW-hr
BSFC		0.539 lb/hp-hr	0.328	kg/kW-hr

Southwest Research Institute - Department of Emissions Research
EPA Hot Transient Emission Test Results
Project No. 03-3227-301

Engine Model:
Engine Desc.: 6.5 L (395 CID) V-8
Engine Cycle: Diesel
Engine S/N:
FTP on Cert.

Test No.: 696 FTPCert.a
Date: 03/12/2003 Time: 14:30
Program HDT: 4.12-R
Cell: 3 Bag Cart: 2

DIESEL Cert., EM-4816-F
HCR: 1.812 FID Resp: 1.00
H= 0.132 C= 0.868 O= 0.000 X= 0.000

Ambient/Test Cell Conditions

Barometer:	28.97	in Hg	98. kPa
Engine Inlet Air			
Temperature:	77.0	°F	25.0 °C
Dew Point:	59.9	°F	15.5 °C
Abs. Humidity:	79.9	gr/lb	11.4 g/kg
Rel. Humidity:	56	%	
Dilution Air:			
Temperature:	78.0	°F	25.6 °C
Abs. Humidity	73.9	gr/lb	10.6 g/kg
Rel. Humidity:	50	%	

Measured Gaseous Data

	Meter	Range	Concentration		
HC Sample	n/a		17.29	ppm	
HC Bckgrd	4.6	2	4.73	ppm	
CO	24.5	2	23.57	ppm	(Dry)
CO Bckgrd	0.7	2	0.67	ppm	
NOx Sample	n/a		14.48	ppm	(Dry)
NOx Bckgrd	1.7	1	0.43	ppm	
CO2 Sample	39.8	1	0.3689	%	(Wet)
CO2 Bckgrd	6.2	1	0.0550	%	

Corrected Concentrations

HC	12.69	ppm
CO	22.38	ppm
NOx	13.77	ppm
CO2	0.3154	%

Mass Emissions

HC	9.150	grams
CO	32.674	grams
NOx	33.446	grams
Particulate	2.375	grams
CO2	7.235	kg
Fuel	5.07 lb	2.30 kg

Sample Flows

	scfm	scmm
Blower 1 Rate:	2,202.9	62.39
Blower 2 Rate:	0.0	0.00
90 mm System:		
Gas Meter 1:	1.83	0.05
Gas Meter 2:	4.16	0.12
Sample Rate:	2.33	0.07
Total Flow Rate:	2,205.22	62.45

Particulate Data

Filter Number:	3188.0-74 (pair)	
Weight Gain:	2.507	mg
Sample Multiplier:	0.947	

Correction Factors

NOx Humidity CF:	1.013
Dry-to-Wet CF, Sample:	0.980
Dry-to-Wet CF, Bckgrd:	0.983
Dilution Factor:	36.39

Test Cycle Data

Sample Time:	1,204.60	sec		
Work:	9.34	hp-hr	6.96	kW-hr
Reference Work:	9.61	hp-hr	7.17	kW-hr
Total Volume (Vmix):	44,273.5	scf	1,253.85	scm

Brake-Specific Emission Results

BSHC (Cell)	0.980	g/hp-hr	1.314	g/kW-hr
CO	3.498	g/hp-hr	4.691	g/kW-hr
NOx (Cell)	3.581	g/hp-hr	4.802	g/kW-hr
Particulate	0.254	g/hp-hr	0.341	g/kW-hr
CO2	774.6	g/hp-hr	1,038.78	g/kW-hr
BSFC	0.543	lb/hp-hr	0.330	kg/kW-hr

Analyzed: 05/09/2003 13:38

Southwest Research Institute - Department of Emissions Research
EPA Hot Transient Emission Test Results
Project No. 03-3227-301

Engine Model:
Engine Desc.: 6.5 L (395 CID) V-8
Engine Cycle: Diesel
Engine S/N:
FTP on Cert.

Test No.: 697 FTPCert.b
Date: 03/12/2003 Time: 15:09
Program HDT: 4.12-R
Cell: 3 Bag Cart: 2

DIESEL Cert., EM-4816-F
HCR: 1.812 FID Resp: 1.00
H= 0.132 C= 0.868 O= 0.000 X= 0.000

Ambient/Test Cell Conditions

Barometer:	28.97	in Hg	98.1 kPa
Engine Inlet Air			
Temperature:	79.0	°F	26.1 °C
Dew Point:	59.9	°F	15.5 °C
Abs. Humidity:	79.9	gr/lb	11.4 g/kg
Rel. Humidity:	52	%	
Dilution Air:			
Temperature:	78.0	°F	25.6 °C
Abs. Humidity	68.9	gr/lb	9.8 g/kg
Rel. Humidity:	47	%	

Measured Gaseous Data

	Meter	Range	Concentration		
HC Sample	n/a		16.62	ppm	
HC Bckgrd	4.4	2	4.52	ppm	
CO	23.2	2	22.32	ppm	(Dry)
CO Bckgrd	0.1	2	0.10	ppm	
NOx Sample	n/a		14.23	ppm	(Dry)
NOx Bckgrd	1.0	1	0.25	ppm	
CO2 Sample	39.8	1	0.3689	%	(Wet)
CO2 Bckgrd	5.9	1	0.0523	%	

Corrected Concentrations

HC	12.22	ppm
CO	21.73	ppm
NOx	13.72	ppm
CO2	0.3180	%

Mass Emissions

HC	8.811	grams
CO	31.711	grams
NOx	33.303	grams
Particulate	2.352	grams
CO2	7.293	kg
Fuel	5.11 lb	2.32 kg

Sample Flows

	scfm	scmm
Blower 1 Rate:	2,184.7	61.87
Blower 2 Rate:	0.0	0.00
90 mm System:		
Gas Meter 1:	1.82	0.05
Gas Meter 2:	4.13	0.12
Sample Rate:	2.31	0.07
Total Flow Rate:	2,187.01	61.94

Particulate Data

Filter Number: 3209.0-75 (pair)
Weight Gain: 2.488 mg
Sample Multiplier: 0.945

Correction Factors

NOx Humidity CF:	1.013
Dry-to-Wet CF, Sample:	0.981
Dry-to-Wet CF, Bckgrd:	0.984
Dilution Factor:	36.40

Test Cycle Data

Sample Time:	1,214.20	sec		
Work:	9.32	hp-hr	6.95	kW-hr
Reference Work:	9.61	hp-hr	7.17	kW-hr
Total Volume (Vmix):	44,257.8	scf	1,253.41	scm

Brake-Specific Emission Results

BSHC (Cell)	0.945	g/hp-hr	1.268	g/kW-hr
CO	3.402	g/hp-hr	4.563	g/kW-hr
NOx (Cell)	3.573	g/hp-hr	4.792	g/kW-hr
Particulate	0.252	g/hp-hr	0.338	g/kW-hr
CO2	782.5	g/hp-hr	1,049.30	g/kW-hr
BSFC	0.548	lb/hp-hr	0.333	kg/kW-hr

Southwest Research Institute - Department of Emissions Research
EPA Hot Transient Emission Test Results
Project No. 03-3227-301

Engine Model:
Engine Desc.: 6.5 L (395 CID) V-8
Engine Cycle: Diesel
Engine S/N:
FTP on Synthetic

Test No.: 702 FTPSyn.a
Date: 03/13/2003 Time: 09:42
Program HDT: 4.12-R
Cell: 3 Bag Cart: 2

DIESEL Syn., FT-100
HCR: 2.136 FID Resp: 1.00
H= 0.152 C= 0.848 O= 0.000 X= 0.000

Ambient/Test Cell Conditions

Barometer:	29.15	in Hg	98.7 kPa
Engine Inlet Air			
Temperature:	76.0	°F	24.4 °C
Dew Point:	59.8	°F	15.4 °C
Abs. Humidity:	79.1	gr/lb	11.3 g/kg
Rel. Humidity:	57	%	
Dilution Air:			
Temperature:	75.0	°F	23.9 °C
Abs. Humidity	68.5	gr/lb	9.8 g/kg
Rel. Humidity:	51	%	

Measured Gaseous Data

	Meter	Range	Concentration		
HC Sample	n/a		9.66	ppm	
HC Bckgrd	n/a		5.50	ppm	
CO	13.1	2	12.57	ppm	(Dry)
CO Bckgrd	0.2	2	0.19	ppm	
NOx Sample	n/a		12.14	ppm	(Dry)
NOx Bckgrd	0.6	1	0.15	ppm	
CO2 Sample	38.7	1	0.3581	%	(Wet)
CO2 Bckgrd	5.6	1	0.0497	%	

Corrected Concentrations

HC	4.32	ppm
CO	12.09	ppm
NOx	11.76	ppm
CO2	0.3098	%

Mass Emissions

HC	3.209	grams
CO	17.778	grams
NOx	28.717	grams
Particulate	1.090	grams
CO2	7.161	kg
Fuel	5.11 lb	2.32 kg

Sample Flows

	scfm	scmm
Blower 1 Rate:	2,202.2	62.37
Blower 2 Rate:	0.0	0.00
90 mm System:		
Gas Meter 1:	1.81	0.05
Gas Meter 2:	4.09	0.12
Sample Rate:	2.27	0.06
Total Flow Rate:	2,204.49	62.43

Particulate Data

Filter Number:	3210.0-76 (pair)	
Weight Gain:	1.124	mg
Sample Multiplier:	0.969	

Correction Factors

NOx Humidity CF:	1.011
Dry-to-Wet CF, Sample:	0.981
Dry-to-Wet CF, Bckgrd:	0.985
Dilution Factor:	35.42

Test Cycle Data

Sample Time:	1,214.20	sec		
Work:	9.54	hp-hr	7.11	kW-hr
Reference Work:	9.61	hp-hr	7.17	kW-hr
Total Volume (Vmix):	44,611.6	scf	1,263.43	scm

Brake-Specific Emission Results

BSHC (Cell)	0.336	g/hp-hr	0.451	g/kW-hr
CO	1.863	g/hp-hr	2.499	g/kW-hr
NOx (Cell)	3.010	g/hp-hr	4.037	g/kW-hr
Particulate	0.114	g/hp-hr	0.153	g/kW-hr
CO2	750.6	g/hp-hr	1,006.55	g/kW-hr
BSFC	0.536	lb/hp-hr	0.326	kg/kW-hr

Analyzed: 05/09/2003 13:38

Southwest Research Institute - Department of Emissions Research
EPA Hot Transient Emission Test Results
Project No. 03-3227-301

Engine Model:
Engine Desc.: 6.5 L (395 CID) V-8
Engine Cycle: Diesel
Engine S/N:
FTP on Synthetic

Test No.: 703 FTPSyn.b
Date: 03/13/2003 Time: 10:22
Program HDT: 4.12-R
Cell: 3 Bag Cart: 2

DIESEL Syn., FT-100
HCR: 2.136 FID Resp: 1.00
H= 0.152 C= 0.848 O= 0.000 X= 0.000

Ambient/Test Cell Conditions

Barometer:	29.16	in Hg	98.7 kPa
Engine Inlet Air			
Temperature:	76.0	°F	24.4 °C
Dew Point:	59.7	°F	15.4 °C
Abs. Humidity:	78.8	gr/lb	11.3 g/kg
Rel. Humidity:	57	%	
Dilution Air:			
Temperature:	78.0	°F	25.6 °C
Abs. Humidity	83.6	gr/lb	11.9 g/kg
Rel. Humidity:	57	%	

Measured Gaseous Data

	Meter	Range	Concentration		
HC Sample	n/a		8.30	ppm	
HC Bckgrd	n/a		3.61	ppm	
CO	12.9	2	12.38	ppm	(Dry)
CO Bckgrd	0.1	2	0.10	ppm	
NOx Sample	n/a		12.89	ppm	(Dry)
NOx Bckgrd	0.6	1	0.15	ppm	
CO2 Sample	38.2	1	0.3533	%	(Wet)
CO2 Bckgrd	5.4	1	0.0479	%	

Corrected Concentrations

HC	4.79	ppm
CO	11.97	ppm
NOx	12.45	ppm
CO2	0.3067	%

Mass Emissions

HC	3.561	grams
CO	17.594	grams
NOx	30.370	grams
Particulate	1.071	grams
CO2	7.086	kg
Fuel	5.06 lb	2.29 kg

Sample Flows

	scfm	scmm
Blower 1 Rate:	2,199.3	62.29
Blower 2 Rate:	0.0	0.00
90 mm System:		
Gas Meter 1:	1.81	0.05
Gas Meter 2:	4.12	0.12
Sample Rate:	2.30	0.07
Total Flow Rate:	2,201.63	62.35

Particulate Data

Filter Number:	3280.0-77 (pair)	
Weight Gain:	1.119	mg
Sample Multiplier:	0.957	

Correction Factors

NOx Humidity CF:	1.010
Dry-to-Wet CF, Sample:	0.977
Dry-to-Wet CF, Bckgrd:	0.981
Dilution Factor:	35.92

Test Cycle Data

Sample Time:	1,215.20	sec		
Work:	9.41	hp-hr	7.0[illegible]	kW-hr
Reference Work:	9.61	hp-hr	7.1[illegible]	kW-hr
Total Volume (Vmix):	44,590.3	scf	1,262.8[illegible]	scm

Brake-Specific Emission Results

BSHC (Cell)	0.378	g/hp-hr	0.507	g/kW-hr
CO	1.870	g/hp-hr	2.507	g/kW-hr
NOx (Cell)	3.227	g/hp-hr	4.328	g/kW-hr
Particulate	0.114	g/hp-hr	0.153	g/kW-hr
CO2	753.1	g/hp-hr	1,009.86	g/kW-hr
BSFC	0.537	lb/hp-hr	0.327	kg/kW-hr

Analyzed: 05/09/2003 13:38

Southwest Research Institute - Department of Emissions Research
EPA Hot Transient Emission Test Results
Project No. 03-3227-301

Engine Model:
Engine Desc.: 6.5 L (395 CID) V-8
Engine Cycle: Diesel
Engine S/N:
SAT on Synthetic

Test No.: 705 SATSyn.a
Date: 03/13/2003 Time: 13:30
Program HDT: 4.12-R
Cell: 3 Bag Cart: 2

DIESEL Syn., FT-100
HCR: 2.136 FID Resp: 1.00
H= 0.152 C= 0.848 O= 0.000 X= 0.000

Ambient/Test Cell Conditions

Barometer:	29.10	in Hg	98.5 kPa
Engine Inlet Air			
Temperature:	77.0	°F	25.0 °C
Dew Point:	59.9	°F	15.5 °C
Abs. Humidity:	79.5	gr/lb	11.4 g/kg
Rel. Humidity:	56	%	
Dilution Air:			
Temperature:	78.0	°F	25.6 °C
Abs. Humidity	73.5	gr/lb	10.5 g/kg
Rel. Humidity:	50	%	

Measured Gaseous Data

	Meter	Range	Concentration		
HC Sample	n/a		9.18	ppm	
HC Bckgrd	4.9	2	5.03	ppm	
CO	15.7	2	15.08	ppm	(Dry)
CO Bckgrd	0.1	2	0.10	ppm	
NOx Sample	n/a		22.35	ppm	(Dry)
NOx Bckgrd	0.6	1	0.15	ppm	
CO2 Sample	61.7	1	0.5903	%	(Wet)
CO2 Bckgrd	5.4	1	0.0479	%	

Corrected Concentrations

HC	4.38	ppm
CO	14.56	ppm
NOx	21.70	ppm
CO2	0.5446	%

Mass Emissions

HC	3.350	grams
CO	22.007	grams
NOx	54.504	grams
Particulate	1.319	grams
CO2	12.936	kg
Fuel	9.21 lb	4.18 kg

Sample Flows

	scfm	scmm
Blower 1 Rate:	2,191.6	62.07
Blower 2 Rate:	0.0	0.00
90 mm System:		
Gas Meter 1:	1.82	0.05
Gas Meter 2:	4.11	0.12
Sample Rate:	2.29	0.06
Total Flow Rate:	2,193.87	62.13

Particulate Data

Filter Number:	3281.0-78 (pair)	
Weight Gain:	1.377	mg
Sample Multiplier:	0.958	

Correction Factors

NOx Humidity CF:	1.012
Dry-to-Wet CF, Sample:	0.977
Dry-to-Wet CF, Bckgrd:	0.983
Dilution Factor:	21.53

Test Cycle Data

Sample Time:	1,253.80	sec		
Work:	17.67	hp-hr	13.18	kW-hr
Reference Work:	17.95	hp-hr	13.39	kW-hr
Total Volume (Vmix):	45,844.7	scf	1,298.35	scm

Brake-Specific Emission Results

BSHC	(Cell)	0.190 g/hp-hr	0.254	g/kW-hr
CO		1.245 g/hp-hr	1.670	g/kW-hr
NOx	(Cell)	3.085 g/hp-hr	4.136	g/kW-hr
Particulate		0.075 g/hp-hr	0.100	g/kW-hr
CO2		732.1 g/hp-hr	981.75	g/kW-hr
BSFC		0.521 lb/hp-hr	0.317	kg/kW-hr

Southwest Research Institute - Department of Emissions Research
EPA Hot Transient Emission Test Results
Project No. 03-3227-301

Engine Model:
Engine Desc.: 6.5 L (395 CID) V-8
Engine Cycle: Diesel
Engine S/N:
SAT on Synthetic

Test No.: 706 SATSyn.b
Date: 03/13/2003 Time: 14:10
Program HDT: 4.12-R
Cell: 3 Bag Cart: 2

DIESEL Syn., FT-100
HCR: 2.136 FID Resp: 1.00
H= 0.152 C= 0.848 O= 0.000 X= 0.000

Ambient/Test Cell Conditions

Barometer:	29.08	in Hg	98.5 kPa
Engine Inlet Air			
Temperature:	77.0	°F	25.0 °C
Dew Point:	57.4	°F	14.1 °C
Abs. Humidity:	72.6	gr/lb	10.4 g/kg
Rel. Humidity:	51	%	
Dilution Air:			
Temperature:	78.0	°F	25.6 °C
Abs. Humidity	68.5	gr/lb	9.8 g/kg
Rel. Humidity:	46	%	

Measured Gaseous Data

	Meter	Range	Concentration		
HC Sample	n/a		9.15	ppm	
HC Bckgrd	4.4	2	4.52	ppm	
CO	16.2	2	15.56	ppm	(Dry)
CO Bckgrd	0.1	2	0.10	ppm	
NOx Sample	n/a		21.14	ppm	(Dry)
NOx Bckgrd	0.5	1	0.13	ppm	
CO2 Sample	61.2	1	0.5851	%	(Wet)
CO2 Bckgrd	5.5	1	0.0488	%	

Corrected Concentrations

HC	4.84	ppm
CO	15.04	ppm
NOx	20.56	ppm
CO2	0.5385	%

Mass Emissions

HC	3.700	grams
CO	22.754	grams
NOx	50.758	grams
Particulate	1.288	grams
CO2	12.800	kg
Fuel	9.12 lb	4.14 kg

Sample Flows

	scfm	scmm
Blower 1 Rate:	2,193.5	62.12
Blower 2 Rate:	0.0	0.00
90 mm System:		
Gas Meter 1:	1.82	0.05
Gas Meter 2:	4.11	0.12
Sample Rate:	2.29	0.06
Total Flow Rate:	2,195.83	62.19

Particulate Data

Filter Number:	3282.0-79 (pair)	
Weight Gain:	1.343	mg
Sample Multiplier:	0.959	

Correction Factors

NOx Humidity CF:	0.994
Dry-to-Wet CF, Sample:	0.978
Dry-to-Wet CF, Bckgrd:	0.984
Dilution Factor:	21.72

Test Cycle Data

Sample Time:	1,253.50	sec		
Work:	17.35	hp-hr	12.94	kW-hr
Reference Work:	17.95	hp-hr	13.39	kW-hr
Total Volume (Vmix):	45,874.5	scf	1,299.19	scm

Brake-Specific Emission Results

BSHC (Cell)	0.213	g/hp-hr	0.286	g/kW-hr
CO	1.311	g/hp-hr	1.759	g/kW-hr
NOx (Cell)	2.926	g/hp-hr	3.923	g/kW-hr
Particulate	0.074	g/hp-hr	0.100	g/kW-hr
CO2	737.7	g/hp-hr	989.34	g/kW-hr
BSFC	0.526	lb/hp-hr	0.320	kg/kW-hr